NRL Memorandum Report 5597

A Simulation of High Latitude F-Layer Instabilities in the Presence of Magnetosphere-Ionosphere Coupling

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July 8, 1985

This research was partially supported by the Defense Nuclear Agency under Subtask QIEQMXBB, work unit 00005, work unit title "Plasma Structure Evolution," and by the National Aeronautics and Space Administration and the Office of the Naval Research.

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 5597	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Research Laboratory 6b. OFFICE SYMBOL (If applicable) Code 4780	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION DNA, ONR and NASA 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20305 Arlington, VA 22203 Washington, DC 20546	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61153N PROJECT NO. (See page ii) TASK NO. WORK UNIT ACCESSION NO. (See page ii)

11. TITLE (Include Security Classification)

A Simulation of High Latitude F-Layer Instabilities in the Presence of Magnetosphere-Ionosphere Coupling

12. PERSONAL AUTHOR(S)

Mitchell, H.G., Jr.,* Fedder, J.A., Keskinen, M.J. and Zalesak, S.T.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM ______ TO ______	1985 July 8	30

16. SUPPLEMENTARY NOTATION

*Science Applications International Corporation, McLean, VA 22102 (Continues)

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Ionospheric structure, Magnetosphere-ionosphere coupling, High latitude ionosphere, Interchange instabilities, nu sub i << omega

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A magnetic-field-line-integrated model of plasma interchange instabilities is developed for the high latitude ionosphere including magnetospheric coupling effects. We show that the primary magnetosphere-ionosphere coupling effect is to incorporate the inertia of the magnetospheric plasma in the analysis. As a specific example, we present the first simulation of the $E \times B$ instability in the inertial regime, i.e., $\nu_i << \omega$ where ν_i is the ion-neutral collision frequency and ω is the wave frequency. We find that the inertial $E \times B$ instability develops in a fundamentally different manner than in the collisional case ($\nu_i >> \omega$). Our results show that striations produced in the inertial regime are spread and retarded by ion inertial effects, and result in more isotropic irregularities than those seen in the collisional case. Keywords:

nu sub i omega >> omega

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL J. D. Huba	22b. TELEPHONE (Include Area Code) (202) 767-3630 22c. OFFICE SYMBOL Code 4780

DD FORM 1473, 84 MAR 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

10. SOURCE OF FUNDING NUMBERS

PROJECT NO.	WORK UNIT ACCESSION NO.
RR033-02-44	S 14534-0
85-550	DN480-935
	DN580-072

16. SUPPLEMENTARY NOTATION (Continued)

This research was partially supported by the Defense Nuclear Agency under Subtask QIEQMXBB, work unit 00005, work unit title "Plasma Structure Evolution," and by the National Aeronautics and Space Administration and the Office of Naval Research.

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A SIMULATION OF HIGH LATITUDE F-LAYER INSTABILITIES IN THE PRESENCE OF MAGNETOSPHERE-IONOSPHERE COUPLING

I. INTRODUCTION

Recent experimental ground-based, rocket, and satellite (HILAT, DYNAMICS EXPLORER, AUREOL-3) observations in the auroral zone and polar cap ionosphere have indicated the existence of both large [Weber et al., 1984; Basu et al., 1984; Bythrow et al., 1984; Cerisier et al., 1984; Vickrey et al., 1980] and small [Hanuise et al., 1981; Baker et al., 1983] scale density structures and irregularities. Different mechanisms, have been proposed to account for high latitude ionospheric irregularities, e.g., particle precipitation, plasma instabilities, and neutral fluid turbulence [Keskinen and Ossakow, 1983]. Considerable quantitative progress has been made in explaining ionospheric structure using plasma interchange instabilities, e.g., the Rayleigh-Taylor instability [Balsley et al., 1972; Ossakow, 1981] in equatorial spread F, and the $\underset{\sim}{E} \times \underset{\sim}{B}$ and current-convective instabilities in the high latitude ionosphere [Ossakow and Chaturvedi, 1979; Keskinen and Ossakow, 1983]. Recently, Weber et al. (1984) and Cerisier et al. (1984) have invoked the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability to explain large scale density fluctuations in the high latitude ionosphere.

A shortcoming of most past research on the nonlinear theory of the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability as it applies to ionospheric structure is that it has been restricted to the collisional (or non-inertial) regime, i.e., $\nu_i >> \omega$ where ν_i is the ion-neutral collision frequency and ω is the wave frequency. One exception is the recent work of Huba et al. (1985) who studied the nonlinear evolution of interchange instabilities in both the inertial and non-inertial regimes. However, their work was limited to short wavelength turbulence, i.e., $kL >> 1$ where k is the wavenumber and L is the density gradient scale length, which is not applicable to large scale ionospheric structures.

In this letter, we present the first simulation of inertial high latitude ionospheric interchange instabilities (e.g., the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability) with inclusion of magnetospheric coupling effects. The basic conclusions of this study are (1) magnetospheric coupling effects reduce the growth rate of the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability, (2) striations produced by the inertial $\underset{\sim}{E} \times \underset{\sim}{B}$ instability develop in a different manner than in the non-

Manuscript approved April 17, 1985.

inertial ($\nu_i >> \omega$) regime, (3) in configuration space, the striations in the inertial regime are more isotropic and spread out resulting in irregularities oriented perpendicular to those produced in the non-inertial case.

II. MODEL

The physical configuration and assumptions of our model are described as follows. We only consider structure in the plane transverse to the ambient magnetic field, i.e., the xy plane. The F-layer is initially characterized by a 6 to 1 density enhancement with a Gaussian profile of scale size 12 km in the x-direction and uniform in the y-direction, a uniform magnetic field in the z-direction (B_z = 0.5 G), and a background electric field in the y-direction (E_y = .025 V/m). The entire enhancement $\underset{\sim}{E} \times \underset{\sim}{B}$ drifts in the x-direction at a velocity v_x = 0.5 km/sec. A uniform horizontal magnetosphere is assumed above the F-layer linked by the vertical magnetic field lines. The back edge of the F-layer enhancement, relative to the drift, is unstable to the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability, which drives ion Pedersen currents in the F-layer and ion polarization drift currents in the magnetosphere due to the perpendicular electric field mapping along the geomagnetic field. These currents close along the magnetic field via parallel electron currents. Assuming that all ion drifts associated with the perpendicular currents are negligible compared to the $\underset{\sim}{E} \times \underset{\sim}{B}$ drift and that $\underset{\sim}{E}_\perp = -\nabla_\perp \phi$, the equations describing this system are

$$\frac{\partial n}{\partial t} + \nabla_\perp \cdot n \underset{\sim}{v}_{i_\perp} = 0 \tag{1}$$

$$\underset{\sim}{v}_{e_\perp} = \underset{\sim}{v}_{i_\perp} = - \frac{c \nabla_\perp \phi}{B} \times z \tag{2}$$

$$\underset{\sim}{j}_{F_\perp} = - \left(\frac{c n e \nu_i}{B \Omega_i}\right) \nabla_\perp \phi = - \sigma_p \nabla_\perp \phi \tag{3}$$

$$\underset{\sim}{j}_{M_\perp} = - \frac{1}{4\pi} \left(\frac{c^2}{V_A^2}\right) \left[\frac{\partial}{\partial t} + \underset{\sim}{v}_{i_\perp} \cdot \nabla_\perp\right] \nabla_\perp \phi \tag{4}$$

$$0 = \int_F dz \left(\nabla_\perp \cdot \underset{\sim}{j}_{F_\perp}\right) + \int_M dz \left(\nabla_\perp \cdot \underset{\sim}{j}_{M_\perp}\right) \tag{5}$$

where n is the ion (and electron) density, $\underset{\sim}{v}_{e(i)\perp}$ is the perpendicular electron (ion) velocity, $\underset{\sim}{j}_{F\perp}$ and $\underset{\sim}{j}_{M\perp}$ are the F-layer Pedersen and the magnetospheric polarization drift current densities, respectively, σ_p is the F-layer Pedersen conductivity, $V_A = B/(4\pi n m_i)^{1/2}$ is the Alfvén velocity, and ν_i and Ω_i are the ion-neutral collision frequency and ion gyrofrequency, respectively. Using (2)-(4) in (5) yields the potential equation,

$$0 = \nabla_\perp \cdot \left\{\Sigma_p + C_M\left[\frac{\partial}{\partial t} - \left(\frac{c\nabla_\perp\phi}{B} \times z\right) \cdot \nabla_\perp\right]\right\}\nabla_\perp\phi \qquad (6)$$

where the field-line integrated F-layer Pedersen conductivity is

$$\Sigma_p = \int_F dz\ \sigma_p, \qquad (7)$$

and the field-line integrated magnetospheric inertial capacitance is

$$C_M = \frac{1}{4\pi}\int_M dz\ \left(c^2/V_A^2\right). \qquad (8)$$

Since the magnetospheric layer is uniform and the ion flow given by (2) is incompressible, the magnetosphere remains uniform and the continuity equation for this layer may be neglected. The F-layer continuity equation for n may be written as a continuity equation for Σ_p,

$$\frac{\partial}{\partial t}\Sigma_p + \nabla_\perp \cdot \left(\Sigma_p \underset{\sim}{v}_{i_\perp}\right) = 0. \qquad (9)$$

Therefore, the system is completely described by (2), (6) and (9) in the variables Σ_p and ϕ, with C_M a constant capacitance describing the magnitude of magnetosphere-ionosphere coupling.

The numerical methods used to simulate the model equations are described in Zalesak et al. [1982]. The continuity equation (9) is solved numerically using the multi-dimensional flux-corrected techniques of Zalesak [1979], while the potential equation (6) is solved with the incomplete Cholesky conjugate gradient algorithm of Hain [1980]. The simulations are performed on an 100 x 80 cell grid (x,y) with a cell size of 1.0 km x .25 km which is drifting with the enhancement at the $E_y \times B$ velocity. Periodic boundary conditions are assumed in the y-direction, and the grid is initialized with a random 1% density fluctuation.

If Σ_p has scale length $L^{-1} = (1/\Sigma_p)\partial\Sigma_p/\partial x$, the non-inertial ($C_M = 0$) growth rate for a wave with wave vector k parallel to y is $\gamma_0 = cE_y/BL$ in the regime $kL \gg 1$. For the parameters of our simulation, the maximum (non-inertial) growth rate is $\gamma_0 \approx 0.05$ sec^{-1}. The e-folding distance of $E_\perp$ parallel to B for this wave is about $\lambda_\parallel \sim (\sigma_\parallel/\sigma_\perp)^{1/2} k_\perp^{-1}$ [Völk and Haerendel, 1971], implying that a wave with $k_\perp^{-1} \approx 1$ km has an e-folding distance of 10^3 km parallel to the field and that $E_\perp$ maps well up into the magnetosphere where the e-folding distance is much greater due to the rapid decrease in σ_p. The Alfvén speed is $V_A \sim 10^3$ km/sec so that electric fields of a wave with a growth time of 20 sec map upwards on the order of 10^4 km into the magnetosphere, and C_M has a value of roughly 10^{13} cm (or ~ 10 farad).

The effect of ion inertia on the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability has previously been studied by Ossakow et al. [1978] in the linear regime. Although their results were for Pedersen and polarization drifts at the same altitude, the linear growth rates are effectively the same for our model equations. A non-zero inertia implies the existence of an inertial relaxation rate, $\gamma_i = \Sigma_p/C_M$. The growth rate in the presence of inertia for the short wavelength approximation has two regions of interest, the non-inertial regime

$$\gamma \approx \gamma_0 \qquad \text{for} \qquad 4\gamma_0 \ll \gamma_i \tag{10}$$

and the inertial regime

$$\gamma \approx (\gamma_0\gamma_i)^{1/2} \qquad \text{for} \qquad 4\gamma_0 \gg \gamma_i . \tag{11}$$

Assuming a Σ_p for the F-layer of 8×10^{10} cm/sec (~ 0.1 mho), a typical value of γ_i for the simulation is .008 sec^{-1}, which is in the inertial regime and which reduces the growth rate of the instability from .05 sec^{-1} to .02 sec^{-1}. For our simulation, two cases were run: a non-inertial case for which $\gamma_i = 1.00$ sec^{-1}, and an inertial case for which $\gamma_i = 0.01$ sec^{-1}.

III. RESULTS

The results of the two simulations are shown in Figures 1 and 2. The four panels in each simulation show approximately equal times relative to the linear growth time of the instability. Figure 1 shows the results for the non-inertial $\underline{E} \times \underline{B}$ instability, while Figure 2 shows the results for the inertial case. It is clear that the results of the two cases are very different at later times.

The behavior of the plasma in Figure 1 is typical of that observed in previous $\underline{E} \times \underline{B}$ instability simulations [Keskinen and Ossakow, 1982]. In panel 2, at 104 seconds, we see that early in the nonlinear stage a set of "fingers" has clearly formed. The high density fingers grow outward into the low density plasma while the low density fingers penetrate into the high density cloud. Subsequent nonlinear evolution involves the continued elongation of these fingers with very little apparent change in the size of the structures perpendicular to their long dimension as seen in panels 3 and 4. The original density enhancement has effectively been sliced into a group of sheets parallel to the initial density gradient.

The behavior of plasma and structure formation in Figure 2, the inertial case, is very different. During the time period between panel 1 and panel 2, before 300 seconds, the growth of the instability closely resembles that in Figure 1. There is nonlinear development of long narrow high and low density fingers which move in opposite directions. However, after 300 seconds, the behavior changes radically. In panels 3 and 4, we see that the fingers form mushroom-like heads and tend to thicken. No longer are there long thin interpenetrating fingers, rather they are fat interpenetrating blobs. Any narrow fingers which begin to form quickly go to a mushroom shape and then spread out. In a number of simulations we have noted a tendency for the structure in the y direction to undergo an inverse cascade to the longest mode which will fit in the system. This feature can clearly be seen in panel 4, where the structured state throughout most of the simulation region shows two blobs; one of high density, the other of low density.

The non-inertial simulation, shown in Figure 1, is characterized by striations with a large value of k_y, which grow in the x-direction without hindrance, completely destroying the initial orientation of the density

enhancement in the y-direction. The inertial simulation, shown in Figure 2, is characterized initially by striations with a large value of k_y, which are hindered in their growth in the x-direction. The plasma at the leading edge of the striation finger is swept to either side and around the striation forming the characteristic mushroom shape. Further evolution involves an inverse cascade in k_y to the minimum value allowed on the numerical grid while simultaneously, the typical value of k_x increases. Consequently, individual enhancements tend to an orientation similar to the original x-directed orientation. Furthermore, the individual enhancements appear to be stabilized to further $\underline{E} \times \underline{B}$ structuring owing to velocity shear along their apparently unstable faces (Perkins and Doles, 1975; Huba et al., 1983).

Interestingly, Rino et al. (1979), Livingston et al. (1982), and Rino and Vickrey (1982) have reported sheet-like structures in the night side auroral region which are aligned perpendicular to the large scale F region ionospheric density gradient. This alignment perpendicular to the density gradient is not easily explained by the traditional instability theory. However, the alignment is similar to the final alignment observed in the inertial simulations.

IV. CONCLUDING REMARKS

Several conclusions can be drawn from our simulations. First, instability-generated electric fields in the high-latitude F-layer may map well up into the magnetosphere, resulting in a much reduced linear growth rate due to the effectively increased ion inertia. Second, the nonlinear development of the instability is fundamentally different in the presence of this coupling; the striations produced are spread and retarded by ion-inertial effects resulting in more isotropic irregularities than in the non-inertial case. The inertial effects may even tend to stabilize the final nonlinear state by producing a velocity shear across normally unstable gradients. The simulation results demonstrate some interesting features which may have been observed in the high latitude nighttime ionosphere.

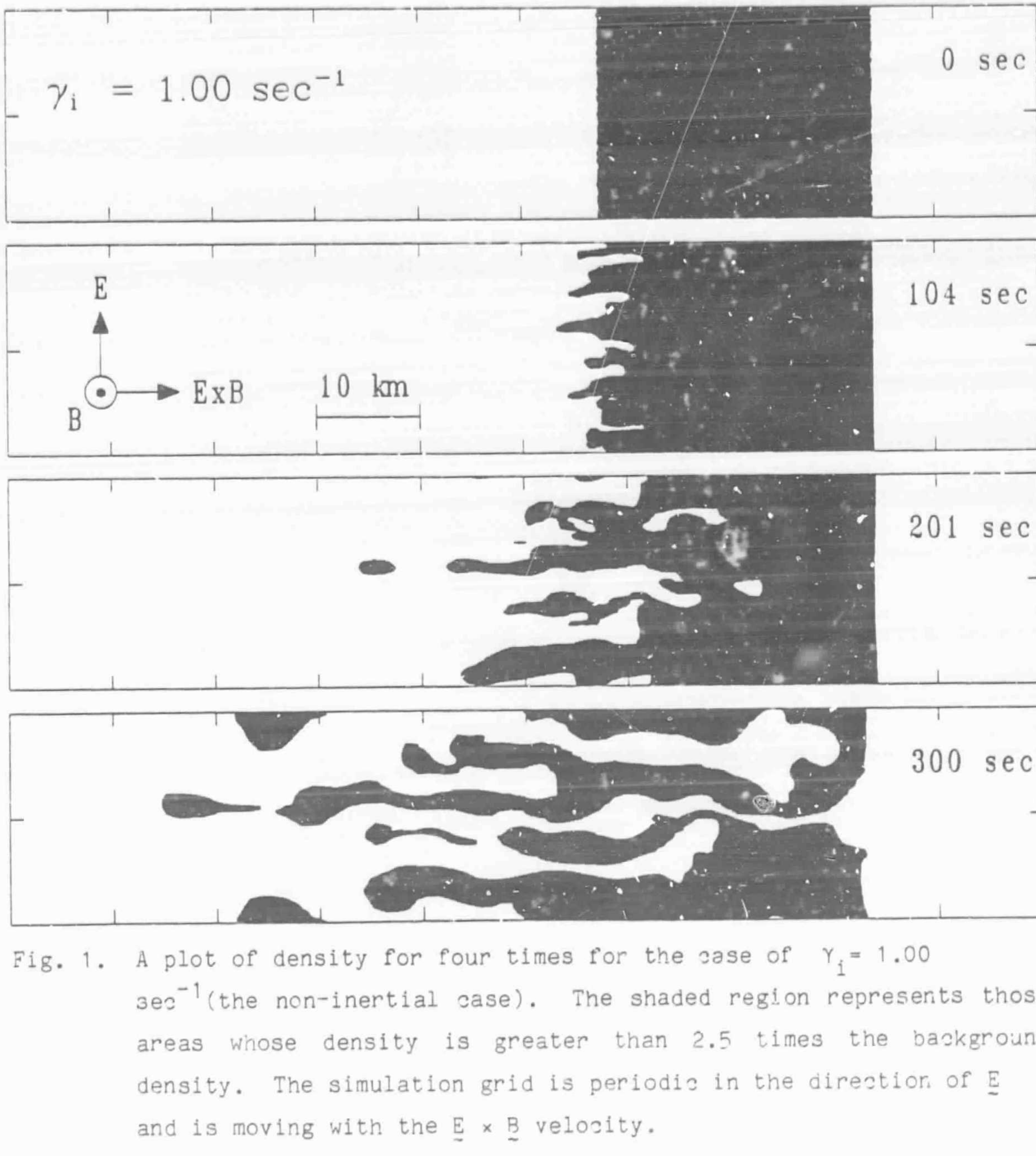

Fig. 1. A plot of density for four times for the case of $\gamma_i = 1.00$ sec^{-1} (the non-inertial case). The shaded region represents those areas whose density is greater than 2.5 times the background density. The simulation grid is periodic in the direction of $\underset{\sim}{E}$ and is moving with the $\underset{\sim}{E} \times \underset{\sim}{B}$ velocity.

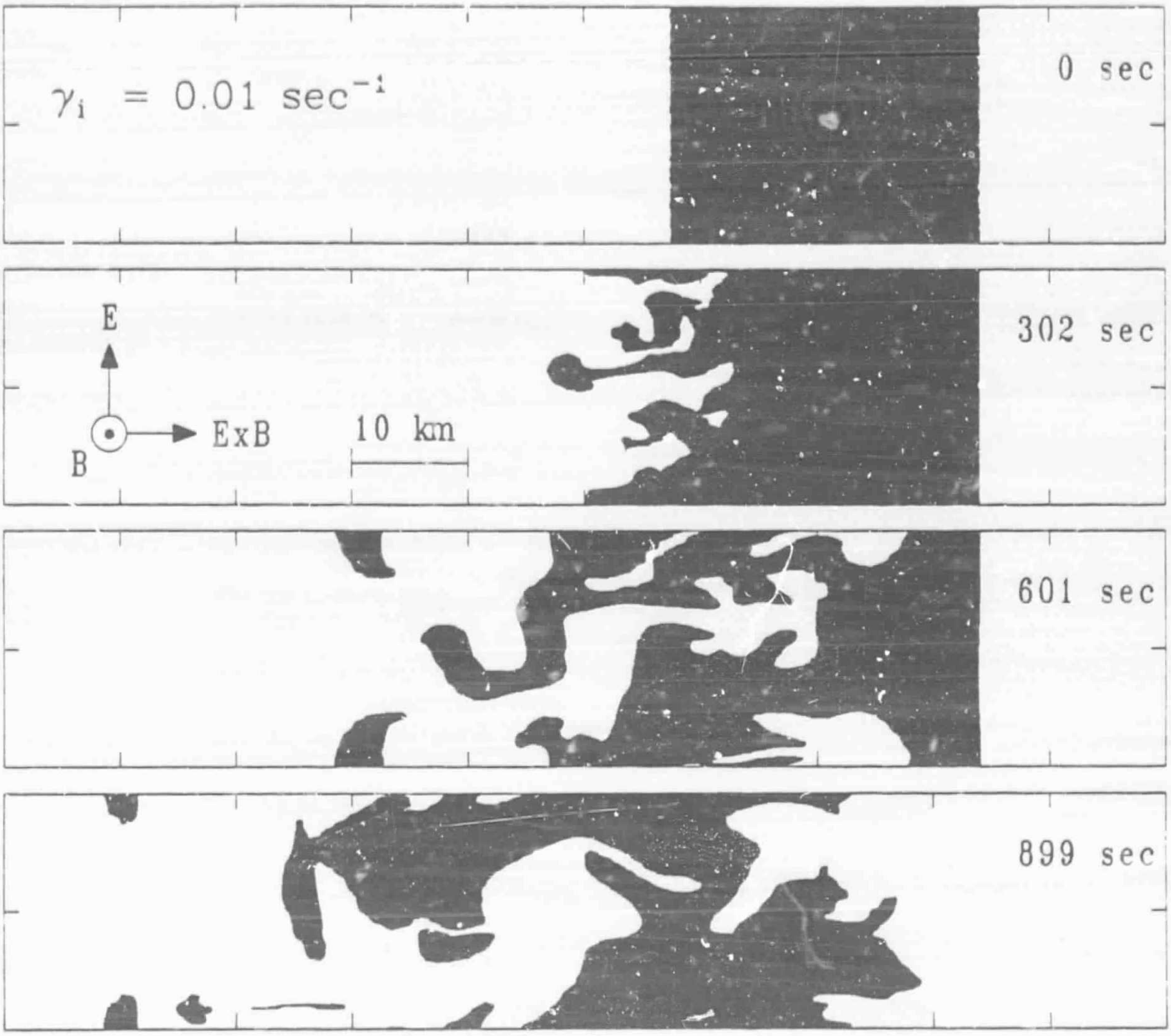

Fig. 2. A plot of density for four times for the case of $\gamma_i = 0.01$ sec^{-1} (the inertial case). The shaded region and the simulation grid are the same as in Fig. 1. The times shown in the two figures are roughly equal multiples of the linear growth time for the instability in the two cases.

Acknowledgments

We thank Dr. J.D. Huba for helpful discussions and a critical reading of the manuscript. This research was supported by the Defense Nuclear Agency, the National Aeronautics and Space Administration, and the Office of Naval Research.

References

Baker, K.B., R.A. Greenwald, and R.T. Tsunoda, Very high latitude F-region irregularities observed by HF-radar backscatter, Geophys. Res. Lett., 10, 904, 1983.

Balsley, B.B., G. Haerendel, and R.A. Greenwald, Equatorial spread F: recent observations and a new intepretation, J. Geophys. Res., 77, 5625, 1972.

Basu, S., S. Basu, E. MacKenzie, W.R. Coley, W.B. Hanson, and C.S. Lin, F region electron density irregularity spectra near auroral acceleration and shear regions, J. Geophys. Res., 89, 5554, 1984.

Bythrow, P.F., T.A. Potemra, W.B. Hanson, L.J. Zanetti, C.-I. Meng, R.E. Huffman, F.J. Rich, and D.A. Hardy, Earthward directed high-density Birkeland currents observed by HILAT, J. Geophys. Res., 89, 9114, 1984.

Cerisier, J.C., J.J. Berthelier, and C. Beghin, Unstable density gradients in the high latitude ionosphere, Radio Sci., 1985, in press.

Hain, K., A non-recursive incomplete Cholesky decomposition method for the solution of linear equations with a sparse matrix, NRL Memorandum Report 4264, Naval Research Laboratory, Washington, D.C. 1980. ADA087005

Hanuise, C., J.P. Villain, and M. Crochet, Spectral studies of F region irregularities in the auroral zone, Geophys. Res. Lett., 8, 1083, 1981.

Huba, J.D., S.L. Ossakow, P. Satyanarayana, and P.N. Guzdar, Linear theory of the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability with an inhomogeneous electric field, J. Geophys. Res., 88, 425, 1983.

Huba, J.D., A.B. Hassam, I.B. Schwartz, and M.J. Keskinen, Ionospheric turbulence: Interchange instabilities and chaotic fluid behavior, Geophys. Res. Lett., 12, 65, 1985.

Keskinen, M.J. and S.L. Ossakow, Nonlinear evolution of plasma enhancements in the auroral ionosphere, 1, Long wavelength irregularities, J. Geophys. Res., 87, 144, 1982.

Keskinen, M.J. and S.L. Ossakow, Theories of high-latitude ionospheric irregularities: a review, Radio Sci., 18, 1077, 1983.

Livingston, R.C., C.L. Rino, J. Owen, and R.T. Tsunoda, The anisotropy of high-latitude nighttime F region irregularities, J. Geophys. Res., 87, 10519, 1982.

Ossakow, S.L., Spread-F theories - a review, J. Atm. Terr. Phys., 43, 437, 1981.

Ossakow, S.L. and P.K. Chaturvedi, Current convective instability in the diffuse aurora, Geophys. Res. Lett., 6, 332, 1979.

Ossakow, S.L., P.K. Chaturvedi, and J.B. Workman, High-altitude limit of the gradient drift instability, J. Geophys. Res., 83, 2691, 1978.

Perkins, F.W. and J.H. Doles, III, Velocity shear and the $\underset{\sim}{E} \times \underset{\sim}{B}$ instability, J. Geophys. Res., 80, 211, 1975.

Rino, C.L., R.C. Livingston, and S.J. Matthews, Evidence for sheet-like auroral ionospheric irregularities, Geophys. Res. Lett., 5, 1038, 1978

Rino, C.L and J.F. Vickrey, Recent results in auroral-zone scintillation studies, J. Atmos. Terr. Phys., 44 875, 1982.

Vickrey, J.F., C.L. Rino, and T.A. Potemra, Chatanika/Triad observations of unstable ionization enhancements in the auroral F-region, Geophys. Res. Lett., 7, 789, 1980.

Völk, H.J. and G. Haerendel, Striations in ionospheric ion clouds, 1, J. Geophys. Res., 76, 4541, 1971.

Weber, E.J., J. Buchau, J.G. Moore, J.R. Sharber, R.C. Livingston, J.D. Winningham, and B.W. Reinisch, F layer ionization patches in the polar cap, J. Geophys. Res., 89, 1683, 1984.

Zalesak, S.T., Fully multidimensional flux-corrected transport algorithms for fluids, J. Comp. Phys., 31, 335, 1979.

Zalesak, S.T., S.L. Ossakow, and P.K. Chaturvedi, Nonlinear equatorial spread F: the effect of neutral winds and background Pedersen conductivity, J. Geophys. Res., 87, 151, 1982.

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to replicate regolith samples that contain agglutinates, shock-damaged particles, and surface-correlated volatiles. How much expense and effort are justified in simulation remains to be determined.

Although some lunar samples will have to be sacrificed for utilization experiments, this sample loss must be minimized. Experience gained from the last sixteen years of lunar sample research will contribute considerably in this effort. For example, consortium studies have been exceptionally productive in bringing diverse disciplines together for studying complex lunar samples; in utilization experiments, a benefit of consortium studies would be the extended life of the sample collection. Sample life may be prolonged by sequential experimentation; for example, experiments on delicate features such as surface-correlated volatiles might precede melting of the same sample for experiments on metal and oxygen production. Innovative research programs must be developed, and will require close liaison between experimenters with different goals. Improved techniques are necessary to obtain critical information from samples much smaller than those normally used in terrestrial studies.

APPLICATIONS WORKSHOP

Communication and cooperation between researchers is vital. An Applications Workshop is being planned, probably to be convened in 1986, that will help to explore research opportunities, to develop an understanding of what can and should be simulated, and to open communications between research groups. Major goals of this workshop would be to (1) encourage experimenters to form consortia, (2) expose utilization experimenters to the available scientific data base on lunar samples, and (3) expose the present lunar sample research community to the data needs of utilization experimenters.

This workshop will probably include a general session on the data available for lunar rocks, minerals, soils, and volatile elements and will cover the prospects for producing useful simulants. Topical sessions will discuss fuel extraction (oxygen, hydrogen, aluminum, and calcium), metal extraction methods (chemical, electrical, thermal, and mechanical), and metal fabrication and the formation of structural materials (concrete, glasses, ceramics, and sintered products). A session on mining and bulk materials processing will encompass regional geology, strip and subsurface techniques, ore processing, and the estimation of probable ores. A session on lunar environmental control and protection will cover the topics of dust, waste, and atmosphere control. A special session must be reserved for fresh ideas about other innovative products and materials for the space environment.

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RELATIONSHIP TO MISSIONS

Lunar sample studies support all NASA planetary missions in a general way by elucidating planetary processes such as volcanism, impact cratering, and planetary differentiation. Sample studies relate *directly* to the Lunar Geoscience Observer, and possibly to other planned missions as well.

LUNAR GEOSCIENCE OBSERVER (LGO)

The Lunar Geoscience Observer might follow the Mars Observer in the Planetary Observer series. Lunar research has provided well-defined scientific goals for this mission, i.e., to resolve the problems outlined here in the section entitled Outstanding Lunar Science Problems. Scientists familiar with lunar samples are actively involved in planning the mission. LAPST intends this involvement to continue into flight teams. Lunar sample results are and will continue to be the primary source of "ground truth" data that will ensure the fullest use of the geochemical and mineralogical global maps to be provided by the LGO mission. Because the upper lunar crust is extensively mixed by impacts, continued sample study will refine and extend the spectrum of lunar primary igneous rock types and is critical to our understanding of regional geochemical compositions, which will undoubtedly be interpreted as mixtures of pristine rock types. The discovery of pristine rock types could greatly alter our perception of the geologic and petrologic significance of geochemical variations that will be mapped by LGO. New laboratory work is needed on the spectral characteristics of a variety of lunar rock types in order to interpret the global maps of lunar spectral reflectance that LGO will obtain. Earth-based telescopic

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spectra have shown us which lunar rock types are potentially relevant to the understanding of lunar spectral data. The larger the spectral data base on lunar samples that is available prior to the LGO mission, the better we will be able to comprehend the abundant and rapidly-returning spectral data from the spacecraft during mission operations. The result: a new understanding of and perspective toward the Moon's composition and evolution that will most likely feed back to more specific sample studies.

SAMPLE RETURN FROM THE MOON AND OTHER BODIES

Sample return missions to various large bodies in the solar system are highly desirable because some fundamental questions can only be answered by making measurements on samples. These bodies include Mars, the Moon, and Venus. However, the rationale for sample returns needs to be addressed. Below are some of the key points that demonstrate the advantages of sample return over *in situ* measurements.

Oblique view of the Aristarchus Plateau (PL) and environs. The fresh, Copernican-age crater Aristarchus (A) is about 42 km in diameter; remote-sensing data indicated the presence of clinopyroxene-bearing, high Th (~18 ppm) rocks —possibly KREEP-rich, plutonic evolved rocks such as granite or quartz monzodiorite. The Plateau itself displays varied geological units including the Imbrium Basin Alpes Formation (an ejecta facies), light plains (P) for which Th contents suggest KREEP lava flows, and extremely red, KREEP-rich pyroclastic dark mantle deposits. Schroter's Valley (S) is a complex, nested sinuous rille, with a morphology that implies a protracted volcanic eruption history. Mare basalts (M) on the horizon span an age from about 3.0 b.y. to possibly less than 2.0 b.y. A future sample return from this area of the Moon has the potential to collect a wide variety of rock types within a relatively limited geographic region.

Sample Return Rationale

Laboratory Equipment Will Always Have Better Resolution and Precision Than Flight Instruments. Over the past ten years, laboratory instruments have undergone major improvements in their ability to analyze increasingly smaller samples and to provide significantly greater resolution of physical and chemical differences and improved precision for isotopic analysis. Because of weight and power limitations, no proposed flight instrument can ever be as good as the best laboratory instrument in its ability to analyze small samples or to detect small differences. This ability is critical to understanding the samples, so laboratory instruments will always provide better data and better understanding of planetary samples. For many types of planetary samples this superior resolution and sensitivity is not only desirable but is absolutely vital to understanding the material. For instance, only by using instruments of very high resolution that can discriminate among individual mineral and glass phases is it possible to understand a planetary regolith. Very precise data are needed for reliable isotope age determinations and isotopic ratios. It is not likely that some kinds of analyses will ever be accomplished to the required precision by remote instruments. Such age and isotopic ratio determinations are critical to the understanding of the geological evolution of a planet and can be used to calibrate other time scales such as those based on crater densities.

Returned Samples Become Resources That Are Accessible in the Future for Rapidly Improving Analytical Technology. Over a period of years, analytical instruments undergo considerable improvements and entirely new instruments are developed. If planetary samples are brought back to terrestrial laboratories, improved or new instruments can be applied to them as they become available. The samples can then be periodically mined for new data. In contrast, flight instruments "freeze" the state of the technology some time before launch and cannot be improved. Only an entirely new mission can take advantage of improvements in instrument technology that may occur from year to year. The technology of mass spectrometry could not support Nd-Sm dating at the time of the Apollo missions, but several years later this technique provided key data on returned lunar samples. Third-generation ion probes and PIXIE analyses now allow trace element determinations on individual mineral and glass grains; such techniques were not available during the Apollo missions.

Unforeseen Key Discoveries Can Lead to New Experimental Design. A package of flight instruments must be chosen and designed well before the mission begins. The choice of the instrument mix and the design of each instrument is entirely dependent on the best guess of what the targeted samples may be like. If the samples are not entirely as expected, the instruments may not work at all, may give the wrong kind of data, or may miss the critical data. An example is an instrument package designed to sample fine particulate material that instead encountered coarse-grained material. If the chemistry of the samples is not as expected, the proper analyzing system may not be included in the package. Flight instruments inevitably lack flexibility and can only do what they are designed to do based on a model for the characteristics of the samples to be analyzed. If the sample characteristics were known perfectly before the flight, the analyses would not be necessary. Hence,

the supposed characteristics are likely to be wrong in some respects and, therefore, the package will not be entirely suitable. Sample return and laboratory instruments allow complete flexibility of instrument types and sample preparation, and even have the ability to handle totally unexpected situations.

There are No Weight/Power Considerations on Laboratory Instruments. Many laboratory techniques require massive or power-hungry devices. Examples include high-resolution mass spectrometers, ion probes, ferromagnetic and nuclear magnetic resonance devices, and synchrotron radiation. A recent example is the Brookhaven synchrotron XRF probe for lunar and meteorite samples. None of these techniques are easily adaptable to flight instruments because of the power and weight limitations.

The Variety and Complexity of Laboratory Instrumentation for Sample Studies are Unlimited. Laboratories contain a variety of very complex instruments. Literally hundreds of different types of instruments and techniques have been applied to lunar samples and have provided a complex variety of data types, all of which have contributed toward understanding the samples. In contrast, only a few different instruments will ever be practical for a flight package. Even if these instruments are equal to their laboratory equivalents, the limited number of instruments will limit the kinds of data that can be acquired. If we had been limited to only five or ten instruments in our analyses of lunar samples, it is doubtful that we would have made much progress in understanding these complex samples. In addition, sterilization requirements can limit the quality and complexity of flight instruments.

OTHER POSSIBILITIES

A central part of NASA's program is the construction of the Space Station. It is difficult to predict how the Space Station will affect lunar science, but we envision several possibilities. One is improved telescopic observations of the Moon from an observatory installed on or near the Space Station. The absence of atmosphere would allow observations of the Moon in a wider range of wavelengths than is possible from Earth's surface, thus providing more chemical and mineralogical information. Such an observatory would supplement the LGO.

Experiments in microgravity and high vacuum could have significance for understanding lunar rock evolution. Such experiments have not yet been designed, but we expect them to be proposed when material research laboratories are in place on the Space Station. The Space Station will be the best place to conduct many lunar-sample utilization studies, for many lunar materials will ultimately be used in orbit for space manufacturing and construction. Again, there is interaction progression between sample studies and sample utilization.

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OUTLOOK FOR CURATORIAL OPERATIONS

It is vital that the curatorial operations continue to support the Planetary Materials and Geochemistry Program (PMGP), at least at the present level of activity. In 1981, the curatorial effort was significantly reduced and has since remained at a constant level of effort, with budget growth sufficient to cover inflationary costs only. The present activity is efficiently supplying the needs of the community and preserving the integrity of the samples.

The active approach of exposing more surfaces and samples for study by the planetary materials community should be continued. Cutting of breccias is stimulating significant research activities. Several research groups have also taken advantage of the chance to pick significant samples from the supplies of 1-4 mm soil fragments. However, detailed cataloging would permit more effective use of these valuable samples. Systematic thin-sectioning and descriptions of regolith breccias have focused the research of several groups on these samples. LAPST will continue to encourage the Curator to actively process the collection.

LAPST will evaluate the need to open specific lunar cores for investigation. The dissection of lunar cores was discontinued in 1981 with approximately one-third of the cores unexamined. Several lunar investigation teams have expressed interest in studying new cores. LAPST will evaluate both the significance of the potential science and the impact on curatorial operations.

LAPST will continue to review the status of the cataloging and documentation of the lunar sample collection. The present set of documentation is uneven in thoroughness and quality. Excellent, thorough reviews in the form of catalogs are available for the Apollo 15 and 16 collections. LAPST will systematically review

the other sample documentation (guidebooks, catalogs, core descriptions, etc.) and identify significant shortcomings. A prioritized plan will be proposed to direct such future curatorial efforts.

LAPST and the Curator will remain ready to take advantage of opportunities to develop new sources of extraterrestrial materials. For example, recently returned Solar Max spacecraft parts have provided samples of captured cosmic dust. The Long Duration Exposure Facility (LDEF) will soon be available as another source. In the new era of replaceable, repairable spacecraft, LAPST expects new opportunities and will encourage use of the curatorial facilities to recover cosmic dust samples.

A significant challenge to the Curator and LAPST is the increasing interest in studies of potential utilization of lunar samples and other extraterrestrial materials. The Planetary Materials Branch is the sole source of lunar materials, and the curatorial staff will identify samples that are suitable for use in such engineering and applied studies. The curatorial staff will be a source of information on suitable simulants for engineering and applied studies. Use of simulants can reduce the demand for lunar material and should be used to pre-test experiments in order to optimize return from studies of actual lunar materials. LAPST recognizes the significant costs of producing simulants but also recognizes the need to have studies done on realistic lunar simulants. Whether major stocks of simulated lunar material should be produced by the Curator is a question that cannot be answered until more is known about the nature, volume, and cost of responding to requests for such materials.